



DESIGN, CONSTRUCTION, MAINTENANCE, AND EVALUATION OF THE MCMURDO SOUND (ANTARCTICA) SEA ICE RUNWAY FOR HEAVY WHEELED AIRCRAFT OPERATIONS

ENGINEERING TECHNICAL LETTER

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14. ABSTRACT This ETL provides design, construction, and maintenance details, dimensional criteria, and structural evaluation guidance for operations of heavy wheeled aircraft at the Sea Ice Runway located on McMurdo Sound near McMurdo Station, Antarctica. This runway is operated by the U.S. Antarctic Program (USAP) and primarily supports Air Force aircraft. These criteria are written specifically for the Sea Ice Runway site in Antarctica. This site does not meet the requirements for a Class B runway. Additionally, some terminology used herein (i.e., in the tables on dimensional requirements) differs from that used in Unified Facilities Criteria (UFC) 3-260-01, Airfield and Heliport Planning and Design. The concepts are generally applicable to any runway composed of sea ice, with or without a thin layer of snow.					
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19 JUL 2006

FROM: AFCEA/CES
139 Barnes Drive, Suite 1
Tyndall AFB FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 06-7: Design, Construction, Maintenance, and Evaluation of the McMurdo Sound (Antarctica) Sea Ice Runway for Heavy Wheeled Aircraft Operations**

1. Purpose. This ETL provides design, construction, and maintenance details, dimensional criteria, and structural evaluation guidance for operations of heavy wheeled aircraft at the Sea Ice Runway located on McMurdo Sound near McMurdo Station, Antarctica. This runway is operated by the U.S. Antarctic Program (USAP) and primarily supports Air Force aircraft. The Sea Ice Runway has previously supported C-130 Hercules, C-141 Starlifter, C-17 Globemaster III, and C-5 Galaxy aircraft. For many years, C-130, C-141, and C-17 aircraft have performed routine operations from an exposed graded sea ice surface; since 2002, they have occasionally operated on a sea ice surface overlain by either a moderately processed thin snow cap or a thin layer of fresh, loose snow.

These criteria are written specifically for the Sea Ice Runway site in Antarctica. This site does not meet the requirements for a Class B runway. Additionally, some terminology used herein (i.e., in the tables on dimensional requirements) differs from that used in Unified Facilities Criteria (UFC) 3-260-01, *Airfield and Heliport Planning and Design*. The concepts are generally applicable to any runway composed of sea ice, with or without a thin layer of snow.

This ETL supersedes ETL 05-2, *Design, Construction, Maintenance, and Evaluation of the McMurdo Sound (Antarctica) Sea Ice Runway for Heavy Wheeled Aircraft Operations*.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force.

2. Summary of Revisions: This ETL is substantially revised and must be completely reviewed.

3. Application: All Department of Defense (DOD) and USAP (managed by the National Science Foundation [NSF]) organizations responsible for the design, construction, maintenance, and evaluation of the McMurdo Sound Sea Ice Runway.

3.1. It is anticipated that all field measurements and data collection prescribed in this ETL can and will be accomplished by knowledgeable personnel in the USAP and

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deployed to Antarctica as part of their occupational performance. This does not preclude Air Force certification teams traveling to McMurdo Station to complete an evaluation; however, due to the logistics, coordination, cost, and uncertain nature of travel to and work in Antarctica, it is more likely that the USAP McMurdo Area Airfields Manager will be responsible for following all ETL guidelines for data collection.

3.2. Only Headquarters Air Mobility Command (HQ AMC) can determine the suitability of the airfield for operations of HQ AMC aircraft. It will be the USAP McMurdo Area Airfields Manager's responsibility to deliver all data and measurements, in the format prescribed in this ETL, to the HQ Civil Engineering Operations Division, Infrastructure Support (AMC/A7OI) contact (see paragraph 11) or his designee. HQ AMC will review the submittal and communicate its findings and decisions back to the airfields manager, who will be responsible for any remedial actions and communicating the airfield status (e.g., open, closed, open with restrictions) to all impacted operational elements. When HQ Civil Engineering Operations Division determines that the airfield meets the criteria specified in this ETL, HQ Operations (AMC/A36AS) will be notified, and they, in turn, will give approval for aircraft operations.

3.3. Authority: Air Force Policy Directive (AFPD) 32-10, *Installations and Facilities*.

3.4. Effective Date: Immediately.

3.5. Ultimate Recipients:

- Air Force civil engineers, USAP, and contractors responsible for the planning, design, construction, maintenance, and evaluation of airfields.
- U.S. Army Corps of Engineers (USACE) and DOD offices responsible for the planning, design, maintenance, and construction of airfields.

3.6. Coordination: HQ Air Mobility Command, Civil Engineering Operations Division, Infrastructure Support (HQ AMC/A7OI).

4. References:

4.1. Air Force:

- AFPD 32-10, *Installations and Facilities*, available at <http://www.e-publishing.af.mil/afpubs.asp>
- Air Force Manual (AFMAN) 32-1076, *Design Standards for Visual Air Navigation Facilities*, available at <http://www.e-publishing.af.mil/afpubs.asp>

- ETL 02-16, *Design, Construction, Maintenance, and Evaluation of the Pegasus Glacial Ice Runway for Heavy Wheeled Aircraft Operations*, available at <http://www.afcesa.af.mil/library/etl.asp?Category=Engineering%20Technical%20Letters>

4.2. Army:

- Cold Regions Research and Engineering Laboratory (CRREL) Monograph 98-1, *Construction, Maintenance, and Operation of a Glacial Runway, McMurdo Station, Antarctica*, available at http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/M98_01.pdf
- FM 5-430-00-1, *Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations – Road Design*, available at <https://atiam.train.army.mil/soldierPortal/atia/adlsc/view/public/10900-1/fm/5-430-00-1/toc.htm>

4.3. Navy:

- Naval Civil Engineering Laboratory Report, *Nomographs for Operating Wheeled Aircraft on Sea-Ice Runways: McMurdo Station, Antarctica*, presented at the Third International Conference on Ice Technology, Cambridge, MA
- Naval Facilities Engineering Service Center, *Landing and Parking Curves for the C-17 Globemaster on Sea Ice: McMurdo Station, Antarctica*, available in Proceedings of the Seventh (1997) International Offshore and Polar Engineering Conference
- Vaudrey, K. 1977, *Ice Engineering – Study of Related Properties of Floating Sea-Ice Sheets and Summary of Elastic and Viscoelastic Analyses*, U.S. Naval Construction Battalion Center, Port Hueneme, CA, Civil Engineering Laboratory, Technical Report R-860

4.4. Joint Service:

- UFC 3-260-01, *Airfield and Heliport Planning and Design*, available at http://65.204.17.188/report/doc_ufc.html

4.5. American Society of Mechanical Engineers

- Barthelemy, J., 1992, *Nomographs for Operating Wheeled Aircraft on Sea-Ice Runways: McMurdo Station, Antarctica*, 11th International Conference on Offshore Mechanics and Arctic Engineering, Calgary, Alberta, June 7–12, 2002, Proceedings, Vol. 4. Edited by Ayorinde, Sinha, Sodhi, and Nixon, p. 27-33, published by the American Society of Mechanical Engineers, New York.

5. Acronyms.

AFJPAM	- Air Force Joint Pamphlet
AFMAN	- Air Force Manual

AFPD	- Air Force Policy Directive
ASTM	- American Society for Testing and Materials
CRREL	- US Army Cold Regions Research and Engineering Laboratory
DO	- Director of Operations
DOD	- Department of Defense
ETL	- Engineering Technical Letter
ft	- foot
HQ AFCESA	- Headquarters, Air Force Civil Engineer Support Agency
HQ AMC/A7OI	- Headquarters, Air Force Mobility Command, Civil Engineering Operations Division, Infrastructure Support
HQ AMC/A36AS	- Headquarters, Air Force Mobility Command, Operations Division
in	- inch
kPa	- kilopascals
MAJCOM	- major command
m	- meter
MMLS	- Mobile Microwave Landing System
MOG	- maximum on ground
NAVAIDS	- navigational aid system
NCEL	- Naval Civil Engineering Laboratory
NSF	- National Science Foundation
PAPI	- precision approach path indicator
PCASE	- Pavement Computer Assisted Structural Engineering
PLZ	- prepared landing zone
psi	- pounds per square inch
REILS	- runway end identifier lights
TACAN	- Tactical Aid to Navigation
VFR	- visual flight rules
UFC	- Unified Facilities Criteria
US	- United States
USACE	- US Army Corps of Engineers
USAP	- United States Antarctic Program

6. Definitions. Some definitions critical to or unique to this ETL are given below.

6.1. Sea Ice Runway Surface: The original exposed or level-graded surface of a floating slab of naturally frozen seawater.

6.2. Non-Instrument Runway: A runway intended for operating aircraft under visual flight rules (VFR). Routine operations at the Sea Ice Runway only occur when sunlight is present; this is roughly from late August until late March each year in the McMurdo Sound area.

6.3. Prepared Landing Zone (PLZ): For the purposes of this ETL, a prepared landing zone (PLZ) refers to a landing zone that is constructed to support routine and moderately frequent (average one to two flights per day) wheeled cargo aircraft traffic, with no adverse effect on airframes, but that is not paved with traditional

construction materials (i.e., asphalt or concrete). The amount of engineering effort required to develop a PLZ depends on the planned operation and the existing surface and weather conditions. Options for surface preparation are governed by the material present at the site and may, at the Sea Ice Runway site, include plowing, grading, planing, and roller compaction.

6.4. Graded Sea Ice Surface: To remove natural undulations in a sea ice surface, including adhered patches of snow, a serrated grader blade is used, often with a laser-guided leveling system, to prepare the runway surface. This surface has a high degree of small-scale (12 to 100 millimeters [0.5 to 4 inches]) roughness which is felt as “chatter” in a fast-moving aircraft.

6.5. Exposed Sea Ice Surface: Whether graded or not, an exposed sea ice surface has little or no snow present to act as a cover. Such a surface will present poor braking resistance at temperatures above -8 °C (18 °F).

6.6. Fresh, Loose Snow Surface: Natural unprocessed snow resting on a graded or natural sea ice surface. Such a cover of snow enhances braking resistance at all temperatures and assists in protecting against the damaging effects of solar heating at temperatures above -8 °C (18 °F). A sea ice runway should never have a fresh loose snow layer greater than 100 millimeters (4 inches) in depth.

6.7. Moderately Processed Snow Surface: A durable weather- and abrasion-resistant surface made from processing (e.g., compacting or tilling) natural snow that overlies the graded sea ice surface. The processed snow surface is smooth and has good braking and solar insolation blocking characteristics. A sea ice runway should never have a processed snow layer greater than 76 millimeters (3 inches) in depth.

6.8. Seasonal Operations: Typically, short-term operations conducted in support of specific local activities. Seasonal operations denote aircraft activities being confined to certain periods of the year when flight and runway conditions are most favorable and when airlift is required. The Sea Ice Runway is only operated when (a) air temperatures are above -50 °C (-58 °F); (b) sunlight is present; and (c) when ice thickness and strength combine to allow safe landing and parking.

7. Dimensional Criteria. Details for establishing airfields for the support of routine operations of Air Force aircraft can be found in UFC 3-260-01. The Sea Ice Runway is unique in a number of ways: seasonal operation only; low volume of air traffic; extremely remote location; sited on a large floating ice mass; limited resources available for construction and maintenance. The criteria are based, for the most part, on Class B runway requirements; however, some terminology used in this ETL differs from that used in UFC 3-260-01.

7.1. Table 1 provides dimensional criteria for the layout and design of the prepared landing zone (PLZ) at the Sea Ice Runway site. Minimum runway length is prescribed by the major command director of operations (MAJCOM/DO), but should

be 3048 meters (10,000 feet) for fully loaded aircraft operations, assuming that the braking conditions are adequate. When the Sea Ice PLZ exists with a thin processed snow pavement, runway strength can vary as a function of air temperature and insolation (solar energy input). Properly executed maintenance operations can mitigate this deterioration and keep the strength at or above minimum levels. The runway length shown in Table 1 also recognizes that the Sea Ice PLZ is at sea level.

Table 1. Sea Ice Runway Dimensional Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	Natural or Graded Sea Ice, or Snow-Capped (Loose or Processed) Operating Surface	Remarks
1	Length (minimum)	See Remarks	Minimum runway length will be determined by the MAJCOM/DO for the most critical aircraft in support of the mission. At the Sea Ice Runway, a runway length of 3048 m (10,000 ft) is considered adequate for all routine operations with C-130, C-141, C-17, and C-5 aircraft.
2	Width	45.7 m (150 ft)	Since the runway is devoid of traditional surface markings, it will appear to be 61 m (200 ft) wide (the width of the runway and the shoulders combined).
3	Width of shoulders (minimum)	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. All snow in shoulders should be prepared to the same degree as that on the runway proper.
4	Longitudinal grade	2% maximum (up or down)	The maximum grade of any tangent, as well as the total elevation change from one threshold of the runway to the other, should not exceed 2%.
5	Longitudinal grade change	No grade change greater than 0.5% is to occur within 305 m (1000 ft) of the runway end.	Hold to minimum practicable. Grades may be both positive and negative but must not exceed the limit specified. Applies to runway and shoulders.

6	Rate of longitudinal grade change	Maximum 0.167% per 30.5 m (100 ft) interval.	Grade changes should be held to a minimum and should be gradual. Application of this criterion will produce a vertical curve having a 182.9 m (600 ft) length for each percent of algebraic difference between the two grades. Applies to runways and shoulders.
7	Transverse grade of runway	1.5% maximum	Transverse grades can be a uniform slope, or crowned at the centerline (a crowned centerline is preferred).
8	Transverse grade of shoulders	2% maximum (down)	For an exposed ice surface, transverse grades should slope down from the runway edge. A snow-capped ice surface may slope upward to a maximum extent of 1%.
9	Width of graded area	Minimum 12.2 m (40 ft)	The graded area is measured from the outside edge of the shoulder. Graded area should routinely have no more than 100 mm (4 in) of loose snow cover. (During clean-up following a drifting event, snow up to 300 mm (12 in) may exist immediately adjacent to runway markers while the runway proper and the shoulders are being maintained to the 100 mm (4 in) standard in order to resume critical flight operations. As soon as is practicable, any drift snow in the graded area must be removed to maintain the overall runway standard.)
10	Transverse grade of graded area	2% maximum (up or down)	Ideally, graded area slope (up or down) should match that of runway shoulders.
11	Width of lateral clear area	79.2 m (260 ft)	The lateral clear area is measured outward from the outside edge of the graded area.

12	Transverse grade of lateral clear area	12% maximum	Requirement is applied to a plane extending outward from the outer edge of the graded area a distance of 36.6 m (120 ft). No object or surface feature may penetrate this plane. Any slope is allowed from 36.6 to 79.2 m (120 to 260 ft) from the outside edge of the graded area (i.e., 79.2 to 122 m [260 to 400 ft] from the runway centerline). No object or surface feature may penetrate this imaginary plane.
13	Width of primary surface	243.9 m (800 ft)	Primary surface is centered about the runway and incorporates the runway, shoulder, graded area, and lateral clear area.

7.2. Shoulders are required along each outside edge of the runway. They must be prepared to the same strength as the runway surface (and be of the same surface material: snow capped or exposed sea ice) and be free of obstacles. Shoulder geometric requirements are presented in Table 1. Figure 1 shows the general layout, including shoulders, and lateral and end clear areas. Turns may take place on the prepared surface, including the shoulders.

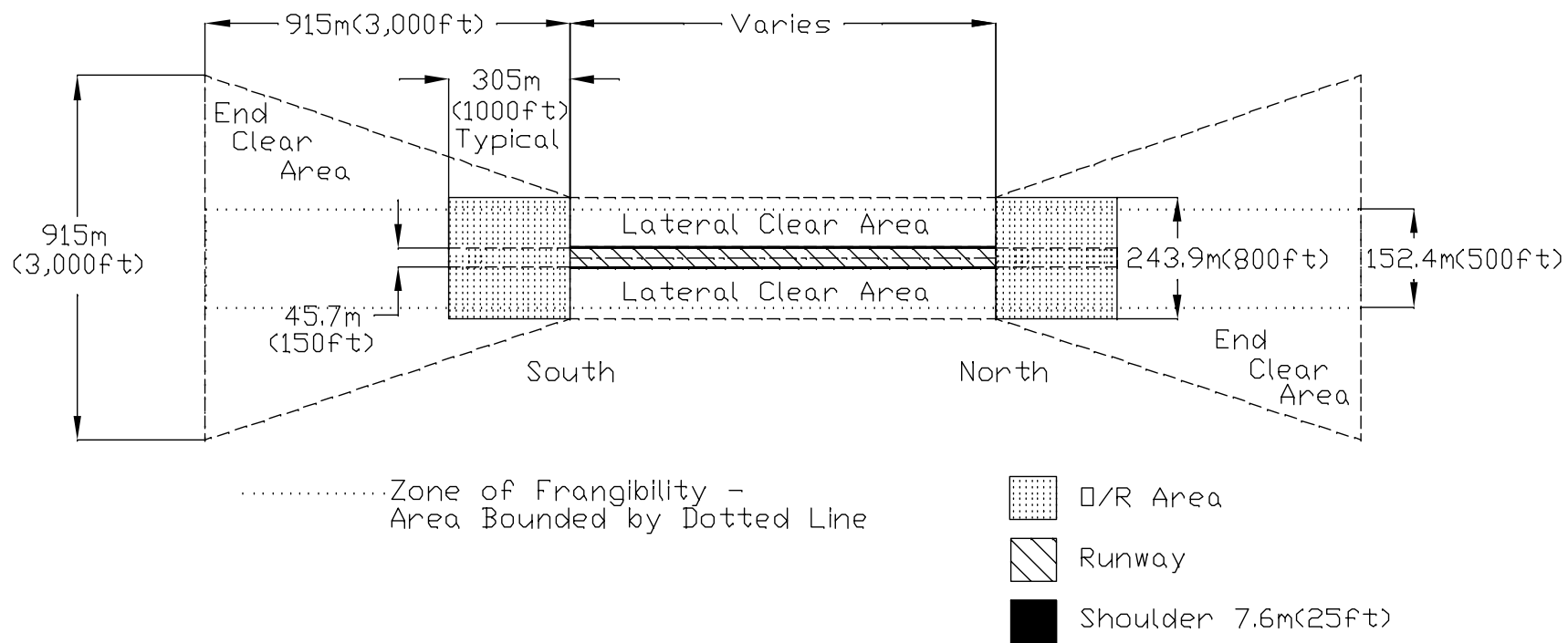


Figure 1. Typical Layout for Airstrip at McMurdo Sound Sea Ice Runway (Not to Scale)

7.3. A runway overrun is required at the departure end of the runway. The overrun must be 305 meters (1000 feet) in length and constructed to the same dimensional and structural standards as the runway surface. At the runway's approach end, runway end lights will be present at the exact threshold.

7.4. Lateral and runway end clear areas are required and their dimensions are given in Table 2. The layout is shown in Figure 1.

Table 2. Sea Ice Runway Overrun and End Clear Area Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	Natural or Graded Sea Ice, or Snow-Capped (Loose or Processed) Operating Surface	Remarks
1	End clear area length	915 m (3000 ft)	Measured along the extended runway centerline. Begins at the runway threshold.
2	Width of inner edge of end clear area	243.9 m (800 ft)	Centered about runway centerline. Begins at runway threshold.
3	Width of outer edge of end clear area	915 m (3000 ft)	Centered about runway centerline.
4	Runway overrun area	See Remarks	The runway overrun area falls within the runway end clear area. The overrun area will be 305 m (1000 ft) long and have a transverse section matching the runway (i.e., include shoulder, graded area, and lateral clear area). See Table 1 for transverse dimensional criteria. The maximum longitudinal grade (up or down) in the overrun area is 2%. The longitudinal grade of the first 91.5 m (300 ft) of the overrun should match that of the last 915 m (3000 ft) of the runway.

5	Approach departure clearance surface	50:1	Approach-departure clearance surface begins at the runway thresholds at the same elevation as the centerline elevation and extends away from the runway 7622 m (25,000 ft). During flight operations, no mobile or fixed object may penetrate this imaginary plane within the end clear area.
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7.5. Taxiways, if present, will have surface strength properties matching those of the runway. Dimensional criteria for taxiways are given in Table 3.

Table 3. Sea Ice Taxiways (If Present) Dimensional Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	Natural or Graded Sea Ice, or Snow-Capped (Loose or Processed) Operating Surface	Remarks
1	Width	22.9 m (75 ft) minimum	Since the taxiway is devoid of traditional surface markings, it will appear to be 38 m (125 ft) wide (the width of the runway and the shoulders combined).
2	Radius of curves (C-130, C-141, C-17, C-5)	22.9 m (75 ft) minimum	Curves in taxiway must be no tighter than the listed minimum turning radii, measured along the taxiway centerline. Fillets at runway/taxiway/apron turns and/or intersections must be 30.5 m (100 ft) minimum radii.
3	Width of shoulder	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Snow in shoulders will be prepared to the same strength as the taxiway.
4	Longitudinal grade	3% maximum	Hold to minimum practicable. Grades may be either positive or negative.

5	Rate of longitudinal grade change	1% maximum over 30.5 m (100 ft)	Grade changes should be held to a minimum and should be gradual. Minimum distance between grade changes is 152.4 m (500 ft). Grade changes cannot exceed 1% measured at 30.5-m (100-ft) intervals. Applies to taxiway and shoulders.
6	Transverse grade of taxiway	3% maximum	Transverse grades can be a uniform slope, or crowned at the centerline (a crowned centerline is preferred).
7	Transverse grade of shoulders	3% maximum	For an exposed ice surface, transverse grades should slope down from the taxiway edge. A snow-capped ice surface may slope upward to a maximum extent of 1%.
8	Runway clearance	76.2 m (250 ft)	Measured from the runway centerline to near edge of the taxiway. Operating aircraft are exempt from runway/taxiway clearance requirements, but operational controls should be implemented to prevent aircraft from operating on both surfaces simultaneously.
9	Infield area		All areas located between the runway and taxiways must be cleared of obstructions.
10	Clearance to fixed or mobile obstacles	61 m (200 ft)	Measured from the taxiway centerline. Operating aircraft are exempt from runway/taxiway clearance requirements, but operational controls should be implemented to prevent aircraft from operating on both surfaces simultaneously.

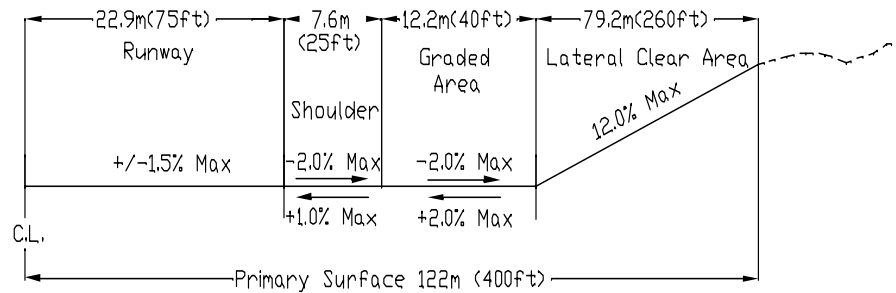
11	Width of lateral clear area	41.9 m (137.5 ft)	Lateral clear area is measured outward from the outer edge of the shoulder. No object or surface feature may penetrate this imaginary plane.
12	Transverse grade of lateral clear area	12% maximum	Grades may slope up or down.

7.6. Aprons, if present, will have surface characteristics and strength properties matching those of the runway. Dimensional criteria for aprons are given in Table 4 and a potential apron configuration is provided in Figure 2.

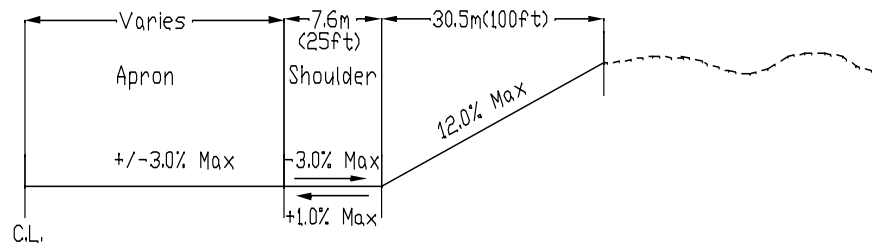
Table 4. Sea Ice Site Apron Requirements for C-130, C-141, C-17, and C-5 Operations

	Description	Natural or Graded Sea Ice, or Snow-Capped (Loose or Processed) Operating Surface	Remarks
1	Apron size	Varies	Sized to accommodate number of aircraft on ground. Maximum visibility and minimum wingtip clearance must be maintained at all times. As a minimum, the pilot must be able to clearly see all parked aircraft when taxiing.
2	Apron grade	3% maximum	Ideally, uniform grade should exist over entire apron area.
3	Width of shoulder	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Snow in shoulders will be prepared to the same strength as the apron.
4	Transverse grade of shoulders	3% maximum	For an exposed ice surface, transverse grades should slope down from the runway edge. A snow-capped ice surface may slope upward to a maximum extent of 1%.
5	Runway clearance	122 m (400 ft)	Measured from the runway centerline to the near edge of the parking apron.

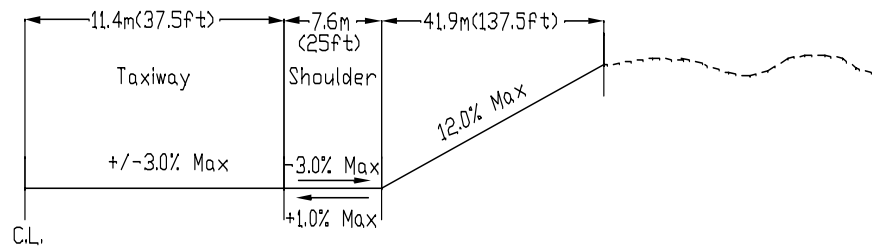
7.7. See Figure 3 for cross-section views of the runway, taxiway, and apron, showing the dimensions from Tables 1, 2, 3, and 4.



RUNWAY TYPICAL SECTION



APRON TYPICAL SECTION



TAXIWAY TYPICAL SECTION

Figure 3. Typical Cross-Section Dimensions for Runway, Taxiway, and Apron (Not to Scale)

8. Structural Criteria

8.1. Sea ice is often categorized as first-year or multi-year ice. This characterization of the ice indicates much about its nature, with multi-year ice having significantly greater complexity. However, for the purposes of a sea ice runway for heavy wheeled aircraft, this ETL will treat both types the same, using overall ice thickness

and ice temperature as governors for ice strength, which ultimately determines its ability to support a given aircraft operation.

Annually, before commencing aircraft operations (flights on the Sea Ice Runway usually begin in early October each season), the Sea Ice Runway will be evaluated using the structural evaluation criteria in this ETL. In addition, the airfields manager will conduct interim evaluations for quality assurance and validation of localized repairs.

8.2. Sea Ice Operating Surface (exposed, graded sea ice surface, or an ice surface overlain by either a moderately processed thin snow cap (less than 50 millimeters [2 inches]) or a thin layer (less than 75 millimeters [3 inches]) of fresh, loose snow).

8.2.1. Sea Ice Runway Evaluation—Deformation Failure. The sea ice surface must be shown to be capable of supporting C-130, C-141, C-17, and C-5 aircraft contact pressure levels without compressive or shear failure. The primary sources of ice surface weakness at the Sea Ice Runway site are (a) melt-pockets and (b) brine leaching features. When these occur, they may show minimal surface expression and may give the runway a deceptive appearance of strength. Rigorous maintenance, including the use of a reflective snow cap, can avoid melt problems. Brine leaching occurs as a function of time, and such weak areas may become prevalent if the runway is sited on progressively older (multi-year) sea ice. Generally, brine leaching features will not reach a point of concern for a sea ice runway until the ice is four years of age or older. If there is any doubt, or if the conditions described in paragraph 8.2.1.2 apply, the runway's structural strength must be certified daily. Adequate surface strength will generally be demonstrated by some form of proof rolling to detect zones of weakness.

8.2.1.1. Proof Rolling. Full-scale proof rolling tests (see CRREL Monograph 98-1) are required before the first flight of the season following sea ice runway construction.

8.2.1.2. During runway operations, if the ice temperature exceeds -5°C (23°F) for an exposed sea ice surface, or -3°C (26.5°F) for a processed or loose snow surface, then a ***rigorous daily visual inspection***, especially in the aircraft wheel tracks, is required. Any surface failure detected will require patching (Attachment 1) and re-certification.

8.2.2. Sea Ice Runway Evaluation—Flexural Failure (Landing and Take-Off).

8.2.2.1. Flexural strength of sea ice is a function of ice temperature, ice thickness and salinity. Correspondingly, the maximum load capacity of sea ice under aircraft loads is a function of flexural strength and the landing-gear-assembly geometry of each aircraft. Determining the maximum allowable aircraft load from ice thickness and temperature measurements establishes the load capacities for landings and takeoffs on the Sea Ice Runway.

8.2.2.2. Ice Temperature Measurement.

8.2.2.2.1. Collecting ice temperature measurements through the entire ice sheet at many locations on a frequent basis along the Sea Ice Runway is onerous using traditional technologies (drilling), so seasonal time periods have been established to simplify the analytical process. The method combines ice *surface* temperatures into “bins,” such that each “bin” represents a period of the operational season. Each time-period contains a maximum and minimum *surface* temperature. Current guidelines divide the operational season (October to February) into four periods:

- Mid-October to late November (Period 1: -20 °C to -10 °C [-4 °F to 14 °F])
- Late November to mid-December (Period 2: -10 °C to -5 °C [14 °F to 23 °F])
- Mid-December to late December (Period 3: -5 °C to -2 °C [23 °F to 28 °F] with at least a small temperature gradient (minimum of 1 °C per meter [0.7 °F per foot] within a vertical column of ice, with the warmest temperatures at the ice surface and cooler temperatures at some depth)
- Late December through January (Period 4: -3 °C to -2 °C [26 °F to 28 °F] with ice temperature uniform throughout an entire vertical column; this is called an “isothermal condition”).

8.2.2.2.2. Collect ice temperatures (measured at a depth of 150 millimeters [6 inches]) at a minimum of four (4) locations on the runway proper and at two (2) locations in the apron/parking area. Temperature data will be collected at a minimum of the following frequencies to verify that the calendar-suggested period is confirmed by ice temperatures. In all cases, actual ice temperatures will govern which period’s standards to apply.

- Period 1: Once every two weeks
- Period 2: Once every week
- Period 3: Three times per week; at least one day between measurements.
- Period 4: Once every day.

8.2.2.3. Ice Thickness Measurement.

8.2.2.3.1. Sea ice thickness is the most critical parameter to be established for calculating safe aircraft operations. Sea ice thickness—much more than ice temperature—tends to be slow to change and quite ubiquitous in the McMurdo Sound region. Its annual trend, irrespective of the initial ice thickness in late August, is well established from more than 20 years of data. However, under some circumstances, ice thickness can

have considerable local variations. When this situation exists, and ice thicknesses are near the limits for desired aircraft operations, a statistical approach is used to establish sea ice thickness.

8.2.2.3.2. Actual ice thickness must be measured at no less than 16 random locations spread throughout the runway surface, with no less than half being located within a 15-meter (50-foot) wide swath down the center of the runway. Ideally, since a statistical approach is used, more measurements will lead to greater confidence levels.

8.2.2.3.3. Thickness measurements must begin at least ten (10) days before the intended onset of flight operations. Measurements will continue throughout the entire duration of flight operations. Measurement frequency will be the same as for temperature measurements (see paragraph 8.2.2.2).

8.2.2.3.4. Increased measurement density is only required during operating periods when the average thickness of the sea ice is nearing the point where it may limit gross aircraft weights and parking times for the aircraft type to be operated. For large aircraft, this will likely be the case any time first-year sea ice is encountered. Attachment 2 describes the process for statistically establishing sea ice thickness.

8.2.2.4. Maximum allowable ice stresses have been determined for each of the four temperature-based operational periods using a computer program designed to calculate the flexural beam strength of sea ice. The allowable stresses have factors of safety between 1.3 and 1.4 (25% to 30% of flexural strength).

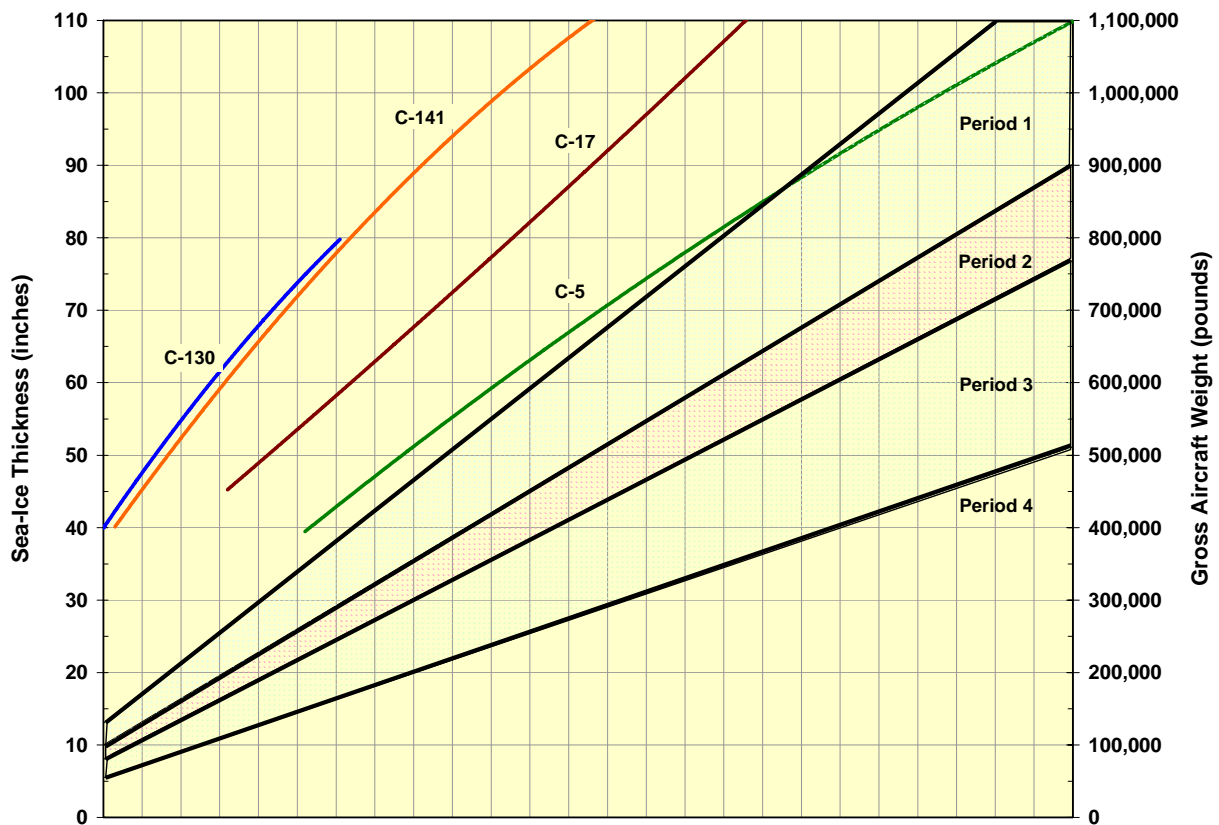
8.2.2.5. Maximum allowable stresses calculated for the four periods of the operational season, combined with ice thickness and landing-gear-assembly geometry, were input to a model developed by the Naval Civil Engineering Laboratory (NCEL) to predict the maximum allowable load of C-130, C-141, C-17 and C-5 aircraft operating on the sea ice in McMurdo Sound. A range of sea ice thickness values experienced throughout the operational season were input and the model calculated the maximum allowable aircraft load given as a function of the Sea Ice Runway thickness and the period of operation. Results from the model are presented in Figure 4 and constitute the operational strength criteria for landing, taxiing, and take-off. The curves in Figure 4 were developed based on the parameters described above, and each is specific to aircraft type and gear assembly geometry. The Figure 4 nomograph may be worked from either direction; that is, if one knows the ice thickness and aircraft type to be operated, the maximum landing and take-off load may be calculated. Conversely, knowing what aircraft type and load are desired to be flown to/from the Sea Ice Runway, the required ice thickness can be determined.

Notes:

(1) The relationship between ice thickness, temperature and aircraft load is specific to each aircraft and cannot be used for any other aircraft. Other aircraft of interest will require a new model run to develop allowable load/thickness curves (see paragraph 11 for contact information if a new analysis is needed).

(2) Examples of use of this nomograph are provided in Attachment 3. See Attachment 6 for metric conversion factors.

(3) The nomograph has limited ability to provide a precise answer because of the thickness of lines on the chart, interpolation of temperature or load within bands on the chart, and an individual's technique. While time-consuming, the model used to develop the nomograph can be operated to produce tabulated results which provide a more user-independent solution. Examples of such tables were produced for the C-17 and are included in Attachment 4.



**Figure 4. Landing and Take-off Nomograph for the
McMurdo Sound Sea Ice Runway
(See Attachment 3 for usage directions and
Attachment 6 for metric conversion factors)**

8.2.3. Sea Ice Runway Surface Evaluation—Creep Failure (Parking).

8.2.3.1. Long-term parking at warm ice temperatures can lead to creep deformation of the sea ice. Long-term parking is defined here to mean any time an aircraft is stationary anywhere on sea ice more than 30 minutes. At ice temperatures below -5°C (23°F), creep deformation is relatively slow. Since the Sea Ice PLZ is operated principally as a “turn-around” runway (i.e., arriving aircraft debark within a few hours, spending limited time on site), it is expected that creep deformation will be negligible. However, if aircraft will be parked for extended time periods, or very heavy loads or thin ice conditions are present, aircraft may have to be moved periodically to avoid excessive creep deformation of the sea ice. A maximum allowable deflection limit of 10% of the ice thickness has been set for parked aircraft. Field tests indicate no major cracking or failures on sea ice until deflections are in excess of 25% of the ice thickness (Vaudrey, 1977). The 10% deflection value was selected because this is the freeboard limit for the ice sheet; although the ice is safe at

this point (10% deflection), water could penetrate through existing cracks and holes to the runway surface, raising concern and causing operational difficulties (Barthelemy, 1992). Parking curves have been developed for each aircraft. The curves indicate the maximum time an aircraft can remain stationary as function of the period (ice temperature), ice thickness and aircraft type and load. The aircraft must change parking locations if it remains on the ice longer than indicated by the curves. The center of the new parking position must be at least 152 meters (500 feet) removed from the original location.

8.2.3.2. Care must also be exercised for other concentrated loads, such as fuel tanks. A similar analysis for the safe residence time for a given concentrated infrastructure load for the prevailing ice temperature and thickness will allow for decisions about total loads and placement geometry. Such infrastructure loads must also be taken into account when locating primary or secondary aircraft parking spots.

8.2.3.3. Operational strength criteria for aircraft parked on sea ice are presented in Figure 5. Contact the person(s) listed in paragraph 11 for recommendations on how to analyze for infrastructure or long-term (12 or more hours) group aircraft parking loads.

Notes:

(1) Examples of nomograph use are provided in Attachment 3. See Attachment 6 for metric conversion factors.

(2) The nomograph has limited ability to provide a precise answer because of the thickness of lines on the chart, interpolation of temperature or load within bands on the chart, and an individual's technique. While time-consuming, the model used to develop the nomograph can be operated to produce tabulated results which provide a more user-independent solution. Examples of such tables were produced for the C-17 and are included in Attachment 4.

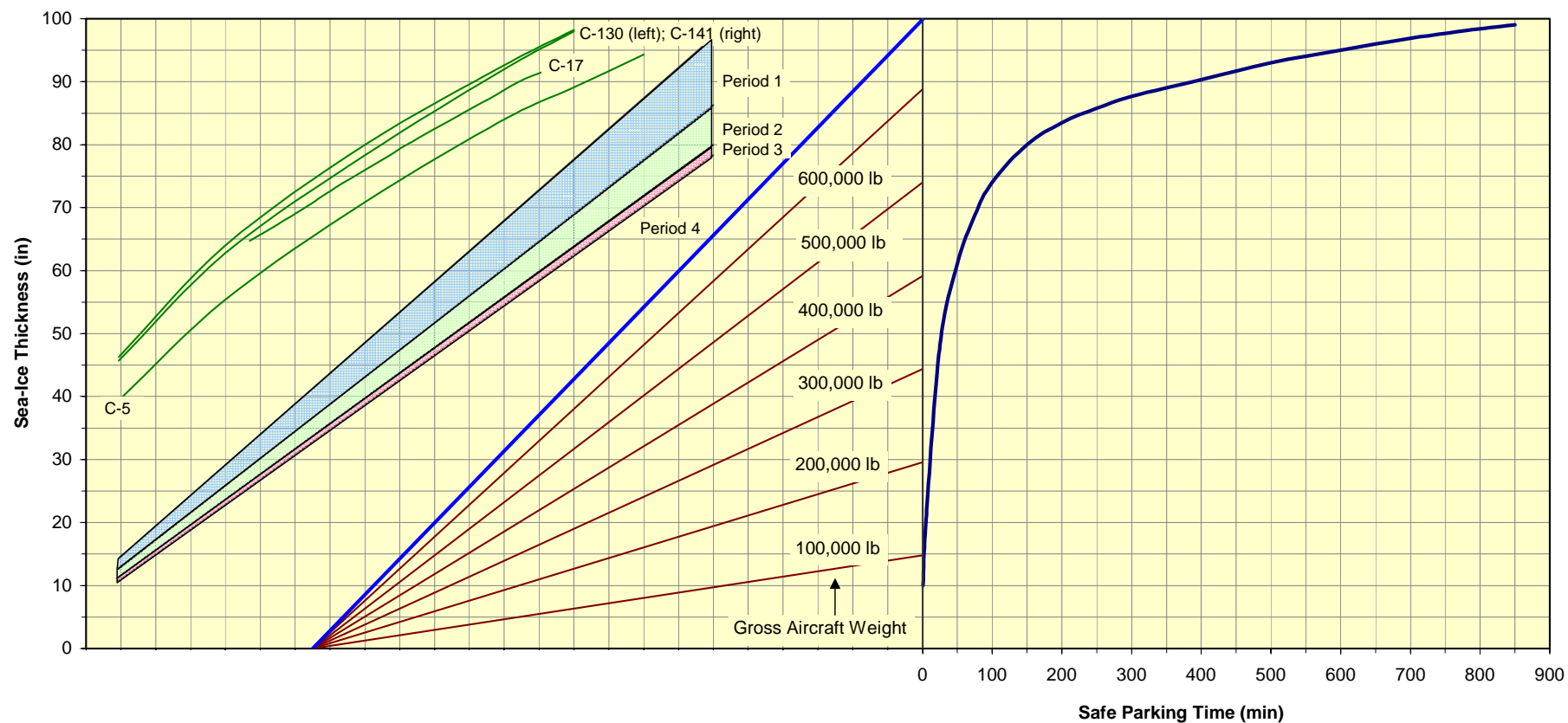


Figure 5. Allowable Parking Times for the McMurdo Sound Sea Ice Runway
 (See Attachment 3 for Usage Directions, Attachment 4 for an Example Conversion of the Nomograph to Solution Tables for the C-17, and Attachment 6 for Metric Conversion Factors)

8.2.4.

WARNING

Both landing/take-off and parking criteria must be determined and compared before each aircraft operation. In most cases, the minimum required sea ice thickness will be different for landing/take-off and for parking. The **GREATER** of the two calculated thicknesses must be used in planning for the aircraft mission. At times, adjustment of one or more controllable variables can allow performing an aircraft mission that, as initially planned, would not be allowed. See examples in Attachment 3 for an illustration of this process.

8.2.5. The primary source of ice mass weakness at the Sea Ice Runway site is weakening during mid- to late-season operations as sea and air temperatures rise. Cracks may also form in the sea ice sheet at any point during the operational season due to tidal and other ice forces active in the region. Though not unsafe, the cracks may limit mobility and must be repaired before aircraft operations. The sea ice crack-repair procedure is described in Attachment 1.

8.2.6. A format for guiding Sea Ice Runway certification is outlined in Attachment 5. Recall that for the runway to be considered structurally adequate for aircraft operations two conditions must be met, as described in paragraphs 8.2.2 and 8.2.3.

8.2.7. This ETL is written specifically for C-130, C-17, C-141, and C-5 aircraft. The load capacity of the Sea Ice Runway changes according to aircraft landing-gear assemblies. Contact the person(s) listed in paragraph 11 for recommendations on how to proceed if operational needs are encountered when the ice thickness and temperature restrict necessary flight operations or if a different type of aircraft or landing gear configuration is proposed for operation on the McMurdo Sound Sea Ice Runway.

9. Markings and Navigational Aid System (NAVAIDS).

9.1. The McMurdo Sound Sea Ice Runway is a VFR-only facility and is operated solely during daylight. However, markings and NAVAIDS are required (a) due to the site's unconventional appearance (light gray to white surface, white surroundings), (b) for compatibility with standard pilot experience, and (c) for periods where landings are required but weather conditions are less than ideal. Initial operation of the Sea Ice Runway was accomplished with an absolute minimum of markings and no NAVAIDS. The use of both markings and NAVAIDS has evolved over the years, and is expected to continue into the future.

9.2. It cannot be overstated that adopting the full extent and type of markings and NAVAIDS found at a conventional airport would create an unmaintainable runway that would be buried by drifting snow in a few seasons. Nor is it necessary for the Sea Ice Runway to have the full complement of available markings and NAVAIDS. Since the airspace is not congested and there are only a few well-known nearby topographic or human-made obstacles, it is operated as a VFR facility.

9.3. Minimizing the number and surface area of markings is desirable for the purpose of reducing runway maintenance and increasing runway availability and longevity. Figure 6 shows the layout of the Sea Ice Runway, including the positions of lead-in, lead-out, ground plane, distance remaining, and threshold and mid-point markers. All markers should be made of durable, lightweight materials. Support posts must be frangible and present a tiny cross-section to the wind to minimize snow drifting, which should be accomplished by a small diameter and a minimum number of posts; bamboo canes are currently used with good results. The markers are ideally of a broad-weave mesh material to minimize the impedance of the wind, both to limit wind loading on the support posts and, more importantly, to reduce snow drifting. Ideally, the base of a marker should be more than 1 meter (3 feet) above the snow surface to avoid snow drifting. This height must be balanced against the need for adequate clearance between the base of an aircraft wing, engine, or propeller and the top of the marker. Currently, TNX Fabric™ (black- and orange-colored plastic mesh fencing material), such as seen at construction sites and ski areas, is used for markers. Note that all markings are well above the runway surface, and no markings are present on the runway itself to depict the runway centerline, shoulder edges, landing zone, or thresholds.

9.4. All structures placed or constructed within the airfield environment are required to be made frangible (to the maximum extent practicable). This applies for any aboveground construction within 76.2 m (250 ft) of the runway centerline and an extension of that dimension for 915 m (3000 ft) beyond the ends of the runway thresholds and within 61 m (200 ft) of the taxiway centerline (except required NAVAIDS). Frangibility implies that an object will collapse or fall over after being struck by a moving aircraft with minimal damage to the aircraft.

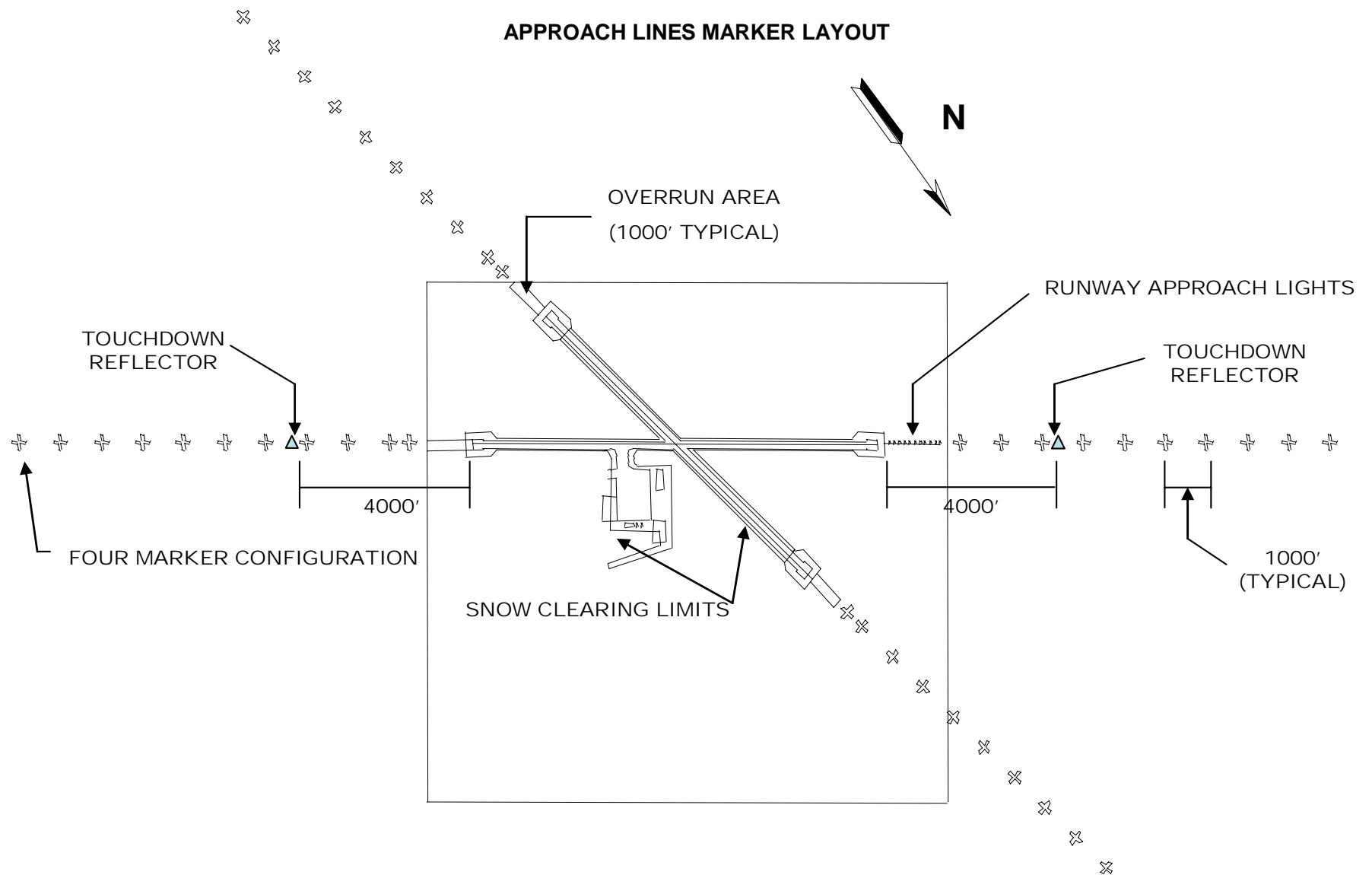
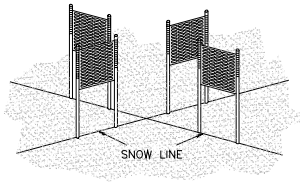
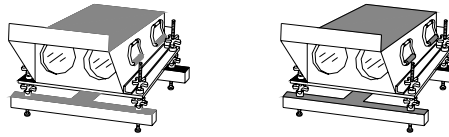


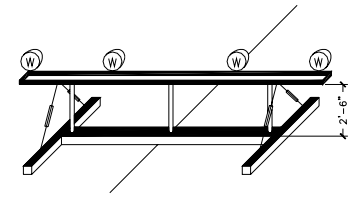
Figure 6. Sea Ice Runway Layout with Dimensions, Showing Markings and NAVAIDS



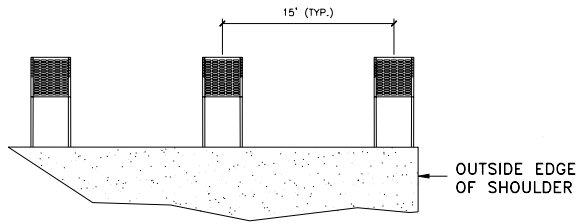
1 FOUR MARKER CONFIGURATION (APPROACH LINES)
C-02 SCALE: NONE



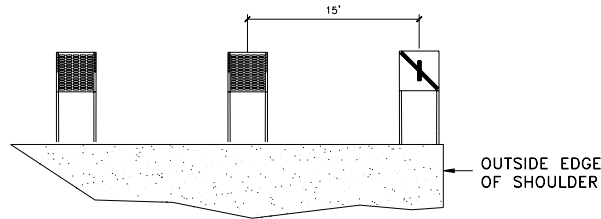
2 PRECISION APPROACH PATH INDICATOR (PAPI)
C-02 SCALE: NONE



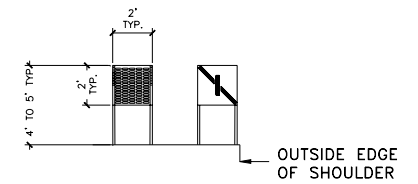
3 APPROACH LIGHTS
C-02 SCALE: NONE



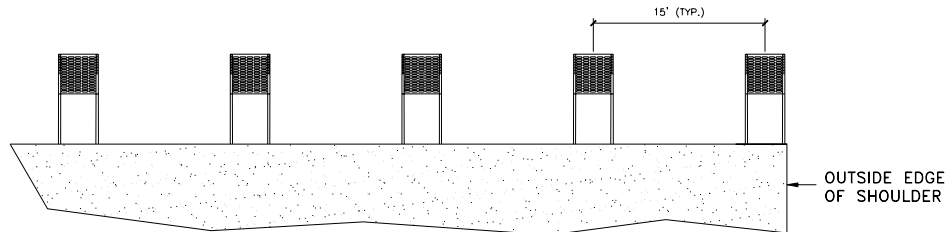
4 GROUND PLANE APPROACH MARKERS
C-02 SCALE: NONE



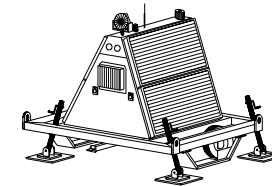
5 GROUND PLANE APPROACH MARKERS
WITH DISTANCE REMAINING MARKER
C-02 SCALE: NONE



7 MARKER DETAILS
C-02 SCALE: NONE



6 THRESHOLD MARKER LAYOUT
RUNWAY MID-POINT MARKER LAYOUT
C-02 SCALE: NONE



2 RUNWAY END IDENTIFIER LIGHTING SYSTEM (REILS)
C-02 SCALE: NONE

**Figure 7. Details of Runway Markers and NAVAIDS
(See Attachment 6 for Metric Conversion Factors)**

9.5. Also shown in Figure 6 are the positions of the current suite of NAVAIDS (Tactical Air Navigation [TACAN], runway end identifier lights [REILS], Mobile Microwave Landing System [MMLS], and precision approach path indicator [PAPI] lights). These are also strictly above-surface installations; however, subsurface wiring has been arranged for the NAVAIDS to allow the use of central and displaced power generation.

9.6. Figure 7 shows details of the runway markings and NAVAIDS. Note that all markings and NAVAIDS are only present at the site during the flight periods. At all other times, all surface structures, including buildings and other support structures, are removed from the site to discourage progressive snow accumulation.

9.7. This ETL reflects markings and NAVAIDS to be used at the Sea Ice Runway site. The markings and NAVAIDS shown in Figures 6 and 7 should be considered completely adequate for routine operations. Exact placement details, including dimensional tolerances of runway markers and NAVAIDS, can be found in Air Force Manual (AFMAN) 32-1076, *Design Standards for Visual Air Navigation Facilities*.

10. Operational Waivers to Criteria. The criteria in this ETL are the minimum permissible for C-130, C-141, C-17, and C-5 operations. When deviations exist or occur, an operational waiver must be obtained before starting flight operations. The airfields manager will initiate a written waiver request to HQ AMC/DO for consideration. The waiver must outline all criteria that do not meet the requirements of this ETL. The appropriate airfield survey team will verify existing PLZ dimensions and grades. HQ AMC is the approval authority for waivers of all criteria contained in this ETL.

11. Points of Contact: Recommendations for improvements to this ETL are encouraged and should be furnished to:

Pavement Engineer
HQ AFCESA/CESC
139 Barnes Dr, Suite 1
Tyndall AFB, FL 32403
DSN 523-6334
Comm (850) 283-6334
Fax DSN 523-6218
Email AFCESAReachBackCenter@tyndall.af.mil

Command Pavement Engineer
HQ AMC/A7OI
507 Symington Drive
Scott AFB, IL 62225-5022
DSN 779-0976
Comm (618) 229-0976
Email amc.a7o@amc.af.mil
("Attn: Command Pavement Engineer" in subject line)

Operations Manager
U.S. Antarctic Program, Office of Polar Programs
National Science Foundation
4201 Wilson Blvd. Suite 755
Arlington, VA 22230
Comm (703) 292-8030
Fax (703) 292-9080

Research Civil Engineer
Applied Research Division
USACRREL
72 Lyme Rd
Hanover, NH 03755-1290
Comm (603) 646-4100
Fax (603) 646-4820

PATRICK G. MUMME, P.E.
Acting Director of Engineering Support

- 7 Atchs
1. Sea Ice Runway Patching Procedure
 2. Example Calculations to Establish Sea Ice Thickness Value
 3. Example Calculations Using Landing and Take-Off and Parking Nomographs
 4. Tabulated Results from Application of Landing/Take-Off and Parking Nomographs to C-17 Aircraft at McMurdo Sound Sea Ice Runway
 5. Test Plan for Sea Ice Runway Wheeled Aircraft Operations Certification
 6. Conversion Factors
 7. Distribution List

SEA ICE RUNWAY PATCHING PROCEDURE

A1.1. Introduction. Infrequently, there may be damage to the runway surface from equipment gouging, solar-induced melt features, or surface melting caused by windborne or spilled contaminants. These areas will require clean-out, repair, and re-certification. The following patching procedure should be followed. Repair these areas by removing the damaged snow and ice and replacing it with a crushed ice and water “patch” (in the sea ice) and a new snow pavement (on the surface) that provides the required hardness/strength. The repair procedure is based on information in CRREL Monograph 98-1, page 57. Note that this procedure is commonly used during runway construction, but when ice temperatures rise above about -6.5 °C (20 °F) this process is largely ineffective because of excessive freeze-up times.

A1.2. Tools. The following tools are needed:

- Long-handled chisel
- Welder’s slag hammer or rock hammer
- Coal shovel
- Source of cold, fresh water

A1.3. Patching Procedure. Thoroughly remove all contaminants (including melted and/or refrozen snow and ice) at the site of the repair and dispose of in accordance with site regulations. Remove any loose but clean snow and ice from the damaged area and place it to the side for later use. Clear the faces and edges of the cavity to allow close inspection of the ice along the sides and bottom.

A1.3.1. Sea Ice.

A1.3.1.1. Use the chisel to excavate the area surrounding the failure area to make certain that all of the weak ice has been dislodged. If a large area of the surrounding ice is weak, use one of the large-scale test methods (see CRREL Monograph 98-1, page 47) to break up the weak ice and identify its limits.

A1.3.1.2. Dispose of sea ice removed from the failed area. Pieces of glacial ice (**not** sea ice) roughly the size of a human fist or smaller should be packed into the cavity to fill the hole slightly above its top (approximately 75 to 100 millimeters [3 to 4 inches] higher). Packed snow may be used in the absence of sufficient glacial ice. Any excess material should be removed from the runway.

A1.3.1.3. Slowly fill the hole containing the crushed ice (or packed snow) with cold **fresh** water (ideally, very near 0 °C [32 °F]) to approximately 75% full. Fill the hole by directing the water around the perimeter of the hole. Mix the ice-water slurry in the hole with the chisel and shovel by vigorous vertical probing to ensure that all pore spaces are filled with water and to encourage water to flow into any cracks radiating into the surrounding ice. If using packed snow, gently push down on the patch with the backside of a shovel only; do not probe and stir with a tool. After about an hour, add water to approximately 50 millimeters (2 inches) below

the surrounding sea ice surface. Smooth the surface with the backside of a shovel. Allow it to cool for 3 to 4 hours, after which time the surface usually will be frozen over.

A1.3.1.4. Using the chisel, break the top of the ice surface in a number of places (10% of total surface area). Slowly re-flood the patch area to fill the air gap under the ice surface with cold **fresh** water.

A1.3.1.5. Use a brightly colored flag (e.g., orange) to mark the location of the patch on the ice surface. A corner of the flag can be frozen into the surface using cold water. If the runway is not in use, a bamboo or plastic pole with a flag can be pushed into the ice-water slurry to mark the location.

A1.3.1.6. Note the approximate location of the patched area, using the runway markers as a guide for the long axis and the knowledge of the runway width for the other axis. If air operations are in effect, the airfields manager, the air traffic controller, and the flight crew coordinator should be notified that a fresh patch is on the runway and that this area should be avoided for at least 48 hours.

A1.3.1.7. Allow the area to freeze for at least 48 hours before allowing traffic to resume; the flag should then be removed. If possible, the patched area should be “dressed” with the chisel-tooth grader blade to blend its edges into the surrounding ice surface and to provide a uniform surface texture.

A1.3.1.8. Following the sea ice repair, the site must be re-certified using the procedures given in paragraph 8.2 et seq. if the repair area is greater than 0.4 square meters (4.3 square feet).

A1.3.2. Snow Cap.

A1.3.2.1. For a runway surface operated with a snow cap, it is required to replace the cap after patching the sea ice.

A1.3.2.2. Fill the area with clean, fresh (not more than one year old) snow using hand tools or mechanical equipment, depending on the volume of snow required.

A1.3.2.3. Level the snow surface with a light drag or snow plane, or a wide-tire (1 meter), low-ground-pressure (tire inflation pressure of 100 kilopascals [kPa] [14.5 pounds per square inch (psi)] or less) wheeled vehicle.

A1.3.2.4. If the snow cap being replaced was processed, use the same procedure originally applied to bring the snow patch to an equivalent level of strength. Allow the snow to “rest” for 24 hours before allowing routine aircraft traffic.

EXAMPLE CALCULATIONS TO ESTABLISH SEA ICE THICKNESS VALUE

A2.1. Twenty runway thickness measurements were made on the sea ice (all measurements in inches): 110, 74, 104, 77, 72, 74, 83, 79, 72, 77, 71, 72, 84, 78, 81, 78, 69, 88, 70, and 74.

A2.2. Rank the measurements in ascending order on a spreadsheet and then calculate the percent of thickness measurements equal to or greater than each unique value.

A2.3. Plot thickness versus percent “equal to or greater than” as shown in Figure A2.1.

A2.4. Enter Figure A2.1 at 85%. Continue to the plotted curve, then down to the Evaluation Thickness of 72 inches for this example.

A2.5. If a test measurement is so low that it is clearly an outlying data point (e.g., 10% less than the next lowest measurement) and therefore not representative of other tests on the runway, then additional tests must be completed to determine the extent of the thin area and whether special consideration is required. When the extent is determined, a separate structural analysis of the thin area may be appropriate, resulting in applying appropriate aircraft weight restrictions to the thin area.

Note: Sea-ice thickness typically increases daily as the season progresses. Therefore, up-to-date thickness measurements are essential to determining the appropriate evaluation thickness.

Thickness Measurement [inches]	Number of Tests Equal to or Greater than Each Value	Percent of Tests Equal to or Greater Than Each Value
69	20	100%
70	19	95%
71	18	90%
72	17	85%
72	17	85%
72	17	85%
74	14	70%
74	14	
74	14	70%
77	11	
77	11	55%
78	9	
78	9	
79	7	35%
81	6	
83	5	
84	4	20%
88	3	15%
104	2	10%
110	1	5%

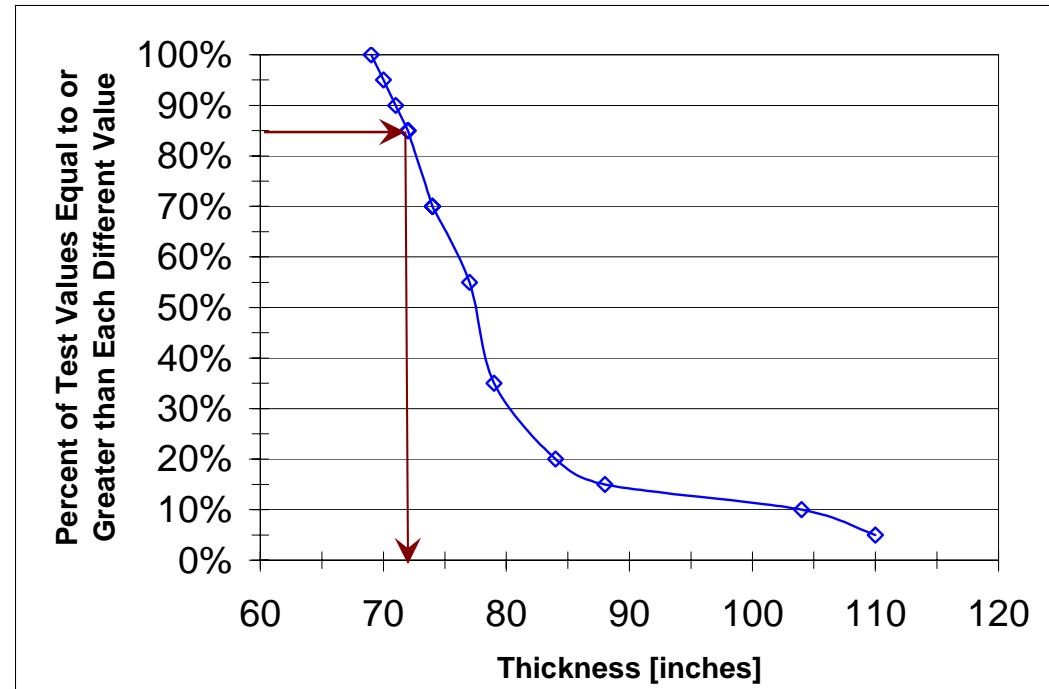


Figure A2.1. Tabular and Graphical Examples of Statistical Analysis of Sea Ice Thickness Data to Determine a Representative Value (Defined as the thickness for which less than 15% of the samples are thinner)

EXAMPLE CALCULATIONS USING LANDING AND TAKE-OFF AND PARKING NOMOGRAPHS

A3.1. Example 1.

A3.1.1. A measured mean sea ice thickness of 1.83 meters (72 inches) exists on McMurdo Sound. The date is 1 November and the measured mean sea ice temperature for the past week is -17°C (1°F). An oversize load, critical to USAP operations, is required in McMurdo. Because of the cargo's size and critical nature, it must be delivered by C-5. In planning for this flight operation, what is the maximum safe gross aircraft landing load given the current sea ice conditions?

A3.1.2. On the landing and take-off nomograph (Figure A3.1) locate 1.83 meters (72 inches) on the left-side vertical axis and draw a horizontal line intersecting the C-5 curve (a). Draw a vertical line from this intersection point to a position representing the scaled location of -17°C (1°F) (vertically between the Period 1 band limits of -20°C (-4°F) (upper line in band) and -10°C (14°F) (lower line in band) (b). From this position, draw a horizontal line to the right-side vertical axis where it can be seen that a maximum C-5 gross weight of 620,000 pounds can be safely supported for take-offs and landings (c).

A3.2. Example 2.

A3.2.1. Preliminary flight planning for the USAP field season favors operating C-17 aircraft well into Period 2 ice conditions. The final C-17 flight is desired for 12 December. The anticipated gross C-17 weight will be about 370,000 pounds for this final flight. What sea ice thickness will be required to support landing this planned flight?

A3.2.2. On the landing and take-off nomograph (Figure A3.2) locate 370,000 pounds on the right-side vertical axis and draw a horizontal line to a position representing the scaled location of 12 December vertically between the Period 2 band limits of about 25 November (upper line in band) and about 15 December (lower line in band) (a). Draw a vertical line from this point to the C-17 curve (b). From this intersection point, draw a horizontal line to intersect the left-side vertical axis, showing that about 78 inches of sea ice must be present for safe take-offs and landings.

A3.2.3. Planners can use historical ice data to determine if there is a good likelihood of this ice thickness being present at a particular time. In any case, as the time nears 12 December, actual measured sea ice thicknesses will govern (via use of the nomograph as depicted in Example 1 [Figure A3.1]) exactly what gross C-17 weight can safely be supported.

A3.3. Example 3.

A3.3.1. The C-5 operation presented in Example 1 (Figure A3.1) determined that a maximum gross weight of 620,000 pounds for landing and take-off is dictated by the sea ice conditions. It is known that about 1.5 hours will be required once the C-5 is

parked for off-loading, refueling, and pre-flight preparations. Can the C-5 at 620,000 pounds safely park on the sea ice for 1.5 hours?

A3.3.2. On the parking nomograph (Figure A3.3) locate 72 inches on the left-side vertical axis and draw a horizontal line to intersect with the C-5 curve (a). Then draw a vertical line from this intersection point to a position representing the scaled location of -17°C (1°F) vertically between the Period 1 band limits of -20°C (-4°F) (upper line in band) and -10°C (14°F) (lower line in band) (b). From this position, draw a horizontal line to a point representing the gross aircraft weight (vertically scaled location between provided weight curves) (c). Now draw a vertical line upward to the reflection surface (d). A horizontal line from the reflection surface is then drawn to intersect the parking curve (e). Lastly, a vertical line is then drawn to intersect the horizontal safe parking time axis where it can be seen that the C-5 mission considered will only allow about 25 minutes of parking time before creep failure of the sea ice.

A3.3.3. Two possibilities exist for alleviating this situation. First, and easiest, is to minimize the gross weight of the C-5. While the landing nomograph (Figure A3.1) indicates that a maximum gross weight of 620,000 pounds can be landed safely, a lesser weight is certainly also safe. If the C-5 gross arrival weight could be reduced to about 475,000 pounds, a parking time of about 90 minutes could be achieved. If the aircraft cannot be reduced to this load level, an alternative is to minimize the landing/parking weight as possible and plan for moving the parked aircraft one or more times during the off-loading process. This is quite inefficient and requires significant planning, but has on occasion been necessary. The distance moved must be greater than two times the overall width of the aircraft (wingspan) and can be in any direction. As soon as the aircraft is parked in its new location, the parking time clock restarts.

A3.4. Example 4.

A3.4.1. A two-hour parking time is required to achieve unloading and back-loading of a C-17 mission very late in the life of the annual McMurdo Sound Sea Ice Runway (30 December). It is expected that the C-17 will have an average weight of 500,000 pounds during a large part of its parked time. What sea ice thickness will be necessary to support this flight?

A3.4.2. On the parking nomograph (Figure A3.4), locate 120 minutes on the horizontal safe parking time axis and draw a vertical line to intersect the parking curve (a). From this intersection point, draw a horizontal line to the reflection surface (b); and from there, drop vertically to the 500,000 pounds aircraft load line (c). A horizontal line from this point to a temperature-representative point within Period 3 follows (d). Then draw a line vertically to intersect the C-17 curve (e). From here, a horizontal line can be seen to intersect the sea ice thickness axis at about 90 inches (f).

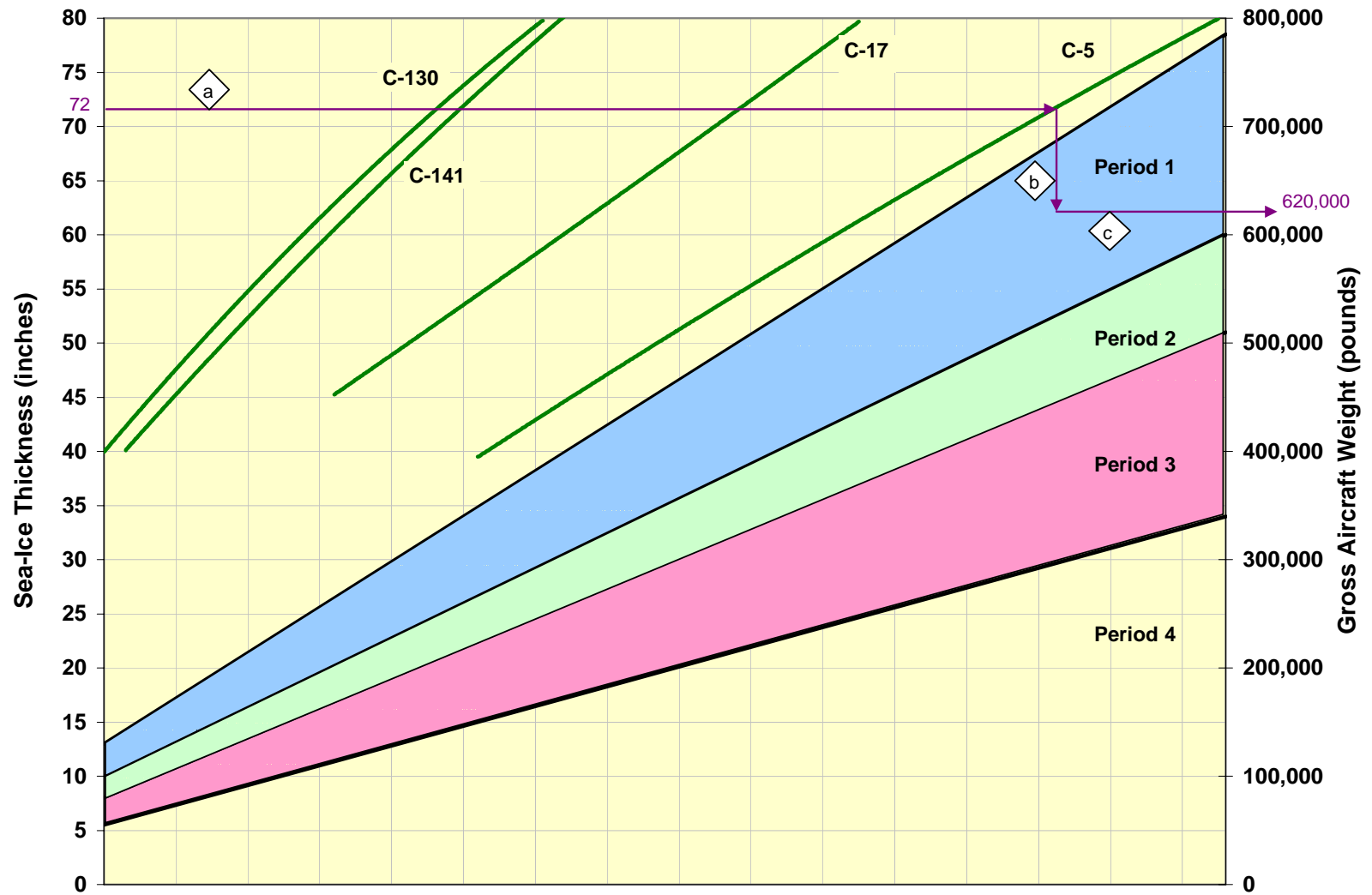


Figure A3.1. Example 1
(See Attachment 6 for Metric Conversion Factors)

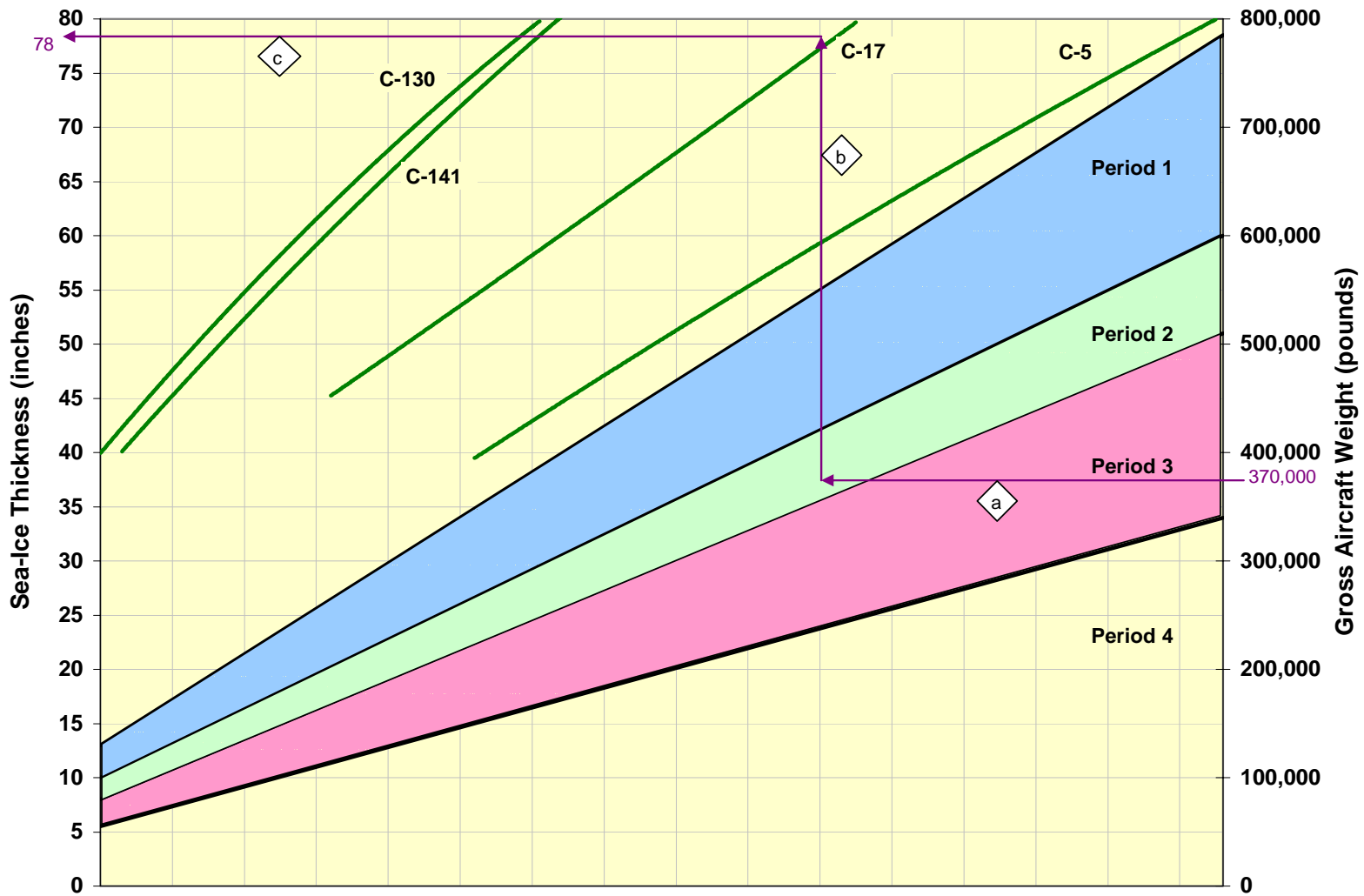


Figure A3.2. Example 2
(See Attachment 6 for Metric Conversion Factors)

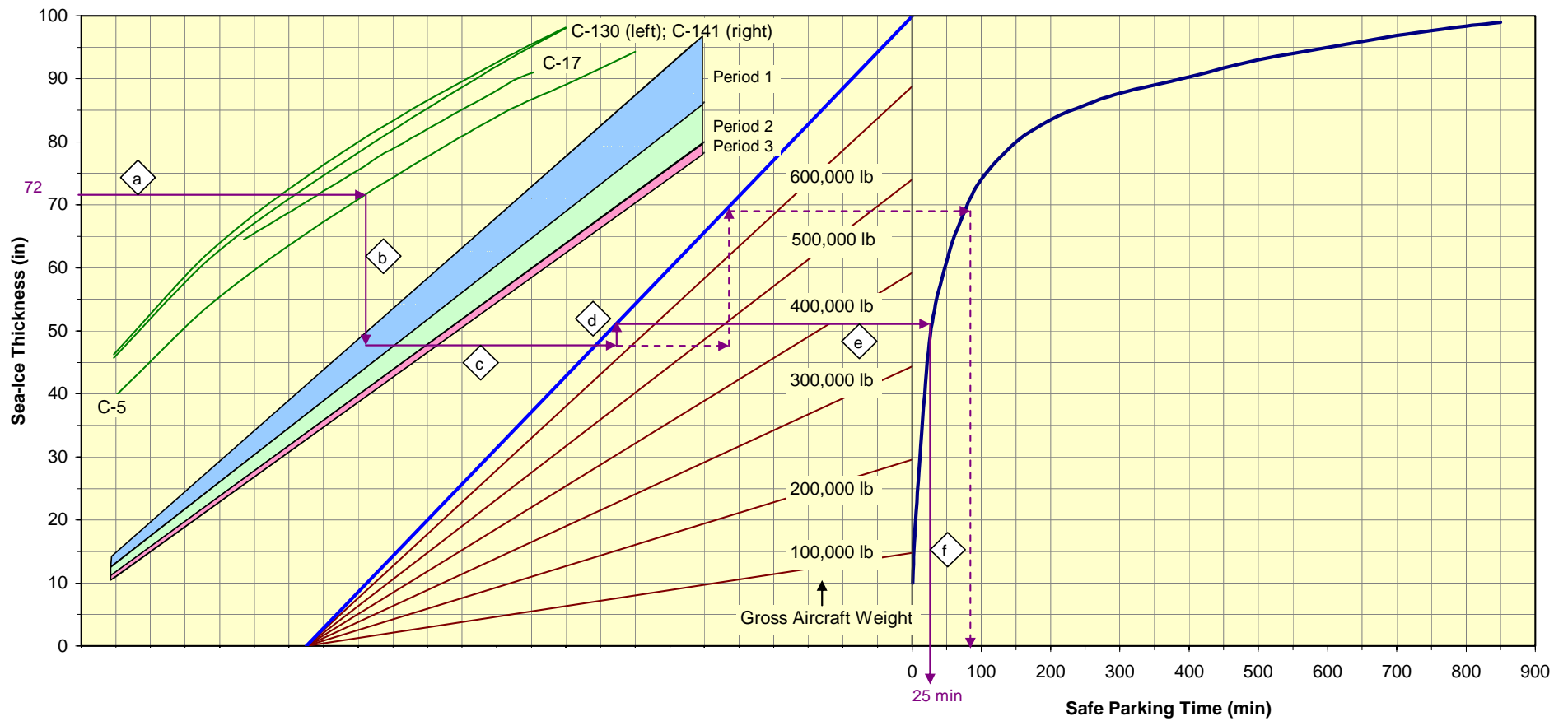


Figure A3.3. Example 3
(See Attachment 6 for Metric Conversion Factors)

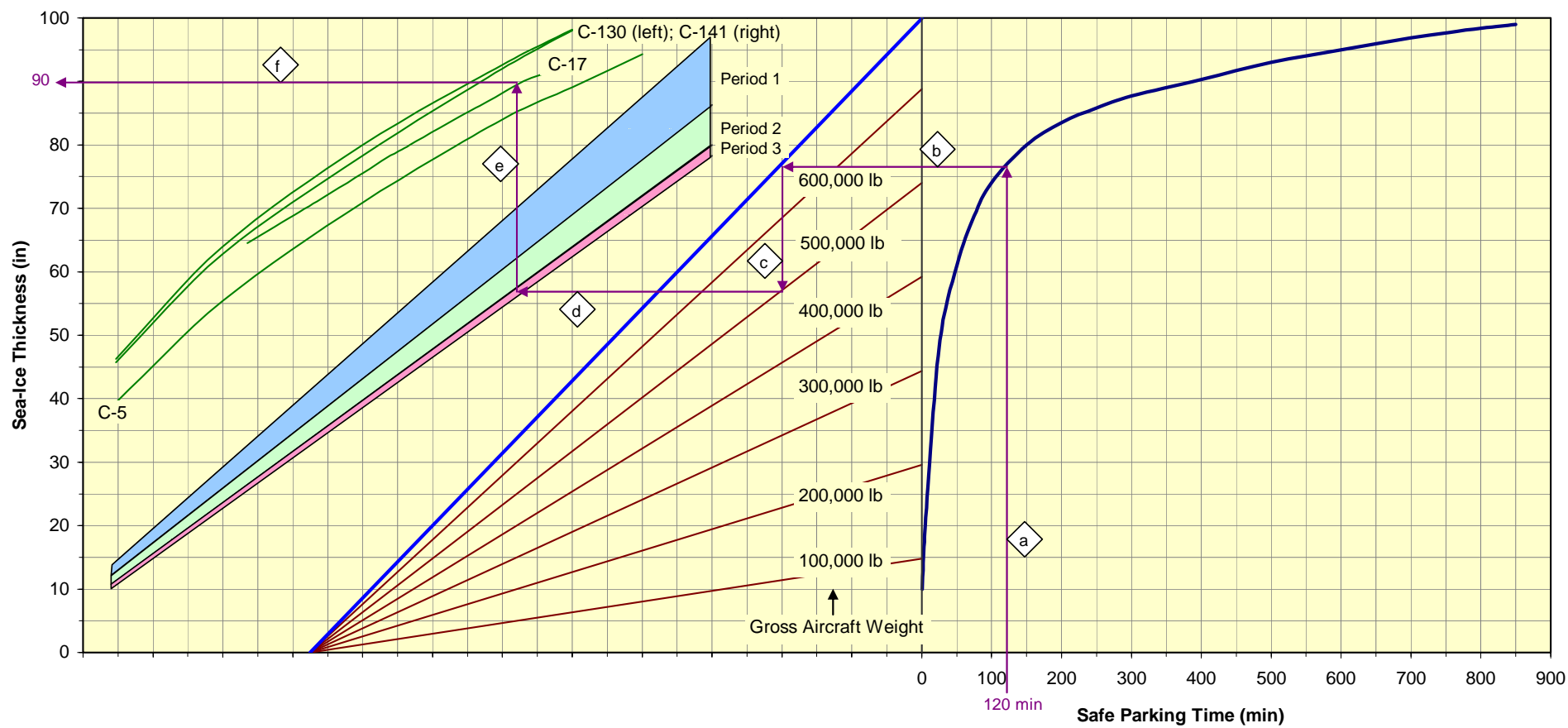


Figure A3.4. Example 4
(See Attachment 6 for Metric Conversion Factors)

**TABULATED RESULTS FROM APPLICATION OF LANDING/TAKE-OFF AND
PARKING NOMOGRAPHS TO C-17 AIRCRAFT AT
MCMURDO SOUND SEA ICE RUNWAY**

A4.1. The nomographs for safe landing/take-off (Figure 4) and safe parking time (Figure 5) have limited ability to provide a precise answer because of the thickness of lines on the chart, interpolation of temperature or load within bands on the chart, and an individual's technique. By applying the mathematical relationships used to generate the nomographs, tables of values for discrete temperatures and loads can be produced. Figure A4.1 depicts the safe landing and take-off loads (in pounds) for the C-17 aircraft between the temperature limits represented by McMurdo Sound Period 1 to Period 4. Figures A4.2 to A4.25 give safe parking times (in hours) for individual temperatures at 10,000-pound (4500-kilogram) increments of gross C-17 weight.

		Ice Temperature (All Period 1, 2 and 3 ice for McMurdo Sound)																						
(deg F)	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	12	10	8	6	4	2	0	-2	-4
(deg C)	-2.2	-2.8	-3.3	-3.9	-4.4	-5.0	-5.6	-6.1	-6.7	-7.2	-7.8	-8.3	-8.9	-9.4	-10.0	-11.1	-12.2	-13.3	-14.4	-15.6	-16.7	-17.8	-18.9	-20.0
44																								272,100
45																							269,100	280,700
46																						266,200	277,500	289,300
47																						274,400	285,900	297,900
48																						282,600	294,200	306,500
49																					271,500	288,800	302,600	315,100
50																					268,800	279,500	289,800	311,000
51																					266,100	276,500	287,500	298,800
52																					273,700	284,300	295,400	307,100
53																					271,100	281,300	292,100	303,400
54																					268,500	278,500	288,800	299,900
55																					266,100	275,800	285,500	296,500
56																					273,200	283,000	293,000	303,000
57																					270,700	280,300	290,300	300,700
58																					268,200	277,500	287,500	297,500
59																					275,000	284,000	293,000	302,000
60																					272,000	280,700	289,300	297,900
61																					269,100	277,500	285,900	294,200
62																					276,500	284,300	292,100	300,700
63																					273,700	281,300	288,800	296,500
64																					271,100	278,500	285,500	292,100
65																					268,500	275,800	282,500	289,300
66																					275,000	282,000	289,000	296,000
67																					272,000	279,000	286,000	293,000
68																					269,100	276,100	283,100	290,100
69																					276,500	283,500	290,500	297,500
70																					273,700	280,700	287,700	294,700
71																					270,700	277,700	284,700	291,700
72																					268,200	275,200	282,200	289,200
73																					275,000	282,000	289,000	296,000
74																					272,000	279,000	286,000	293,000
75																					269,100	276,100	283,100	290,100
76																					276,500	283,500	290,500	297,500
77																					273,700	280,700	287,700	294,700
78																					270,700	277,700	284,700	291,700
79																					268,200	275,200	282,200	289,200
80																					275,000	282,000	289,000	296,000
81																					272,000	279,000	286,000	293,000
82																					269,100	276,100	283,100	290,100
83																					276,500	283,500	290,500	297,500
84																					273,700	280,700	287,700	294,700
85																					270,700	277,700	284,700	291,700
86	274,100																				268,200	275,200	282,200	289,200
87	277,500	295,300																			275,000	282,000	289,000	296,000
88	280,900	298,900	320,300																		272,000	279,000	286,000	293,000
89	284,300	302,600	324,300	345,900																	269,100	276,100	283,100	290,100
90	287,700	306,300	328,300	354,700	386,800																276,500	283,500	290,500	297,500
91	291,100	310,000	332,300	359,100	391,800	432,600															273,700	280,700	287,700	294,700
92	294,500	313,700	336,400	363,500	396,700	438,100	444,900														270,700	277,700	284,700	291,700
93	297,900	317,400	340,400	368,000	401,600	443,600	450,500	457,800	465,400	473,400	481,800	490,700								268,200	275,200	282,200	289,200	
94	301,300	321,000	344,400	372,400	406,600	449,100	456,100	463,500	471,300	479,500	488,100	497,100	506,600	516,700	527,300	534,600	542,600	551,300	559,700	568,000	576,200	584,200	592,000	
95	304,700	324,700	348,400	376,800	411,400	454,600	461,800	469,300	477,200	485,500	494,300	503,500	513,200	523,400	534,200	545,600	556,800	567,800	578,500	589,000	599,300	609,300	619,000	
96	308,100	328,400	352,400	381,200	416,300	460,100	467,400	475,100	483,100	491,600	500,500	509,900	519,700	530,100	541,200	552,000	562,600	573,000	583,100	592,900	602,500	611,900	621,100	
97	311,500	332,100	356,400	385,600	421,200	465,600	473,000	480,900	489,000	497,700	506,700	516,200	526,300	536,900	548,100	559,000	569,600	580,300	590,700	600,800	610,700	620,400	629,900	
98	314,900	335,800	360,400	390,000	426,100	471,100	478,700	486,800	495,000	503,700	512,900	522,600	532,800	543,600	555,000	567,000	578,500	589,700	599,500	609,000	618,300	627,400	636,300	
99	318,300	339,500	364,500	394,400	431,000	476,600	484,300	492,400	500,900	509,800	519,100	528,900	539,400	550,400	562,000	574,200	586,000	597,500	608,700	619,600	629,300	638,800	648,100	
100	321,700	343,100	368,500	398,800	435,900	482,100	489,900	498,200	506,800	515,800	525,400	535,400	546,000	557,100	568,800	580,100	591,100	601,800	612,300	622,500	632,500	642,300	651,900	
101	325,100	346,800	372,500	403,300	440,800	487,600	495,600	503,900	512,700	521,900	531,600	541,800	552,500	563,800	575,800	587,200	598,300	609,000	619,400	629,500	639,300	648,900	658,300	
102	328,500	350,500	376,500	407,700	445,700	493,100	501,200	509,700	518,600	528,000	537,800	548,200	559,100	570,600	582,800	594,600	606,100	617,300	628,200	638,800	649,100	659,100	668,900	
103	331,900	354,200	380,500	412,100	450,600	498,600	506,800	515,500	524,500	534,000	544,000	554,500	565,600	577,300	589,700	601,800	613,600	625,100	636,300	647,200	657,800	668,100	678,100	
104	335,300	357,900	384,500	416,500	455,000	504,100	512,200	520,900	530,400	540,100	550,200	560,800	572,000	583,800	596,300	608,500	620,400	632,000	643,300	654,300	665,000	675,400	685,500	
105	338,700	361,600	388,600	420,900	459,400	508,600	516,800	525,500	535,000	545,100	555,600	566,700	578,300	590,600	602,600	614,300	626,000	637,500	648,800	659,800	670,500	680,900	691,000	
106	342,100	365,200	392,600	425,300	464,300	513,600	521,700	530,400	540,000	550,200	560,900	572,200	584,000	596,500	608,700	620,600	632,300	643,800	655,100	666,100	676,800	687,200	697,300	
107	345,500	368,800	396,600	429,700	470,200	520,600	528,400	537,500	547,600	558,300	569,600	581,500	594,000	606,200	618,100	630,000	641,700	653,200	664,500	675,500	686,200	696,600	706,700	
108	348,900	372,600	400,800	434,200	476,100	527,000	535,400	545,000	555,600	566,900	578,800	591,300	604,400	617,100	630,000	642,500	654,800	666,900	678,800	690,500	701,900	713,000	723,900	
109	352,300	376,300	404,600	438,600	480,000	531,600	540,600	550,100	560,000	570,400	581,300	592,800												

TEST PLAN FOR SEA ICE RUNWAY WHEELED AIRCRAFT OPERATIONS CERTIFICATION

A5.1. Introduction. This test plan documents and explains the required steps, methods, and tools required to certify the Sea Ice Runway for wheeled aircraft operations. The primary attributes that govern certification are dimensions and grades, markings, pavement strength (short and long term), and ice temperature profiles.

A5.2. Certification Process.

A5.2.1. Dimensions and Grades.

A5.2.1.1. Measure features in the runway area (as depicted in Figures 1, 2, and 3). Use available and expedient survey methods and tools (e.g., taping, measuring wheel, transit, laser) to verify that the dimensions and grades of the following airfield components are as required in Tables 1 through 4.

- Runway
- Shoulders
- Overrun area (each end, if present)
- Taxiway
- Apron (refuel, load/unload, turnaround)
- End clear areas
- Lateral clear areas

A5.2.1.2. Verify dimensions and grades of each feature at the approximate locations shown in Figures 1, 2, and 3. Note that some areas and zones will blend seamlessly (without indication) into other areas, such as where the runway width transitions to the shoulders. In these situations, simply measure and verify that the combined dimensions of the features are per specification.

A5.2.1.3. On Figures 1, 2, and 3, place a check mark (✓) by each dimension and grade that has been measured and approved, and place an **X** by any dimension that fails the inspection, noting where the failure is located. Measurements that fail the inspection must be documented and brought to the attention of the airfields manager.

A5.2.2. Markings and NAVAIDS. AFMAN 32-1076 governs the placement of markings and NAVAIDS.

A5.2.2.1. Check that markings and NAVAIDS are in the correct positions and properly annotated as shown in Figure 6.

Note: Direct on-snow marking is prohibited.

A5.2.2.2. Verify that the bottom of the marker (flag) is at least 1 meter (3 feet) above the snow surface. Marker dimensions (which vary depending on required markings) must conform to Figure 7.

A5.2.2.3. Check that flags are attached to frangible (break-away or bend-away) poles. Suitable poles can be made of common bamboo or lightweight plastic, but must not be metal or large, solid wood (e.g., 100-millimeter by 100-millimeter [4-inch by 4-inch] posts).

A5.2.2.4. Each flag will be stretched out between two poles and attached to the poles by means that are wind-proof and sturdy (but removable), such as with clamps and cords.

A5.2.2.5. On Figure 6, place a check mark (✓) by each flag that is properly placed and marked, and place an **X** by any missing, misplaced, or improperly marked flags. Flagging problems must be documented and brought to the attention of the airfields manager.

A5.2.3. Sea Ice Temperature. (**Note:** Required with or without the presence of snow cap on sea ice surface.)

A5.2.3.1. Paragraph 8.2 et seq. indicates the importance of temperature measurements for structural certification. Sea ice temperature is ideally measured with a continuously recording imbedded sensor string located at a number of representative locations. If such sensors are not available, manual temperature readings must be taken during the warmest (air temperature) three-hour period during the day. Collect ice temperatures (measured at a depth of 150 millimeters [6 inches]) at a minimum of four (4) locations on the runway proper and at two (2) locations in the apron/parking area. Temperature data will be collected at a minimum of the following frequencies:

- Period 1: Once every two weeks
- Period 2: Once every week
- Period 3: Three times per week; at least one day between measurements
- Period 4: Once every day

A5.2.3.2 Sea Ice Evaluation Temperature. The sea ice temperature used for evaluating the structural capacity (referred to as the “evaluation temperature”) should be determined by calculating the simple average of the measured temperatures at the (minimum) six locations sampled. For example, if the measured temperatures are 10, 12, 13, 11, 14 and 10 °F, the evaluation temperature is equal to $(10+12+13+11+14+10) \div 6 = 11.7$ °F. The evaluation temperature is then used, with sea ice thickness to determine safe landing and parking parameters.

A5.2.4. Sea Ice Thickness.

A5.2.4.1. The sea ice thickness used for evaluating the structural capacity (referred to as the “evaluation thickness”) should be determined using a statistical approach applied to the set of measured thickness data points. The evaluation thickness should be equal to or less than 85% of all the measured thicknesses. This corresponds to an evaluation thickness of one standard deviation below the mean. If 10 or less thickness measurements are made, then the lowest of the measured values should be used as the evaluation thickness. An example procedure for determining the evaluation thickness is detailed in Attachment 2.

A5.2.4.2. Actual ice thickness must be measured at no less than 16 random locations spread throughout the runway surface, with no less than half being located within a 15-meter (50-foot) wide swath down the center of the runway. Ideally, since a statistical approach is used, more measurements will lead to greater confidence levels. Thickness measurements must begin at least ten (10) days before the intended onset of flight operations. Measurements will continue throughout the entire duration of flight operations. Measurement frequency will be the same as for temperature measurements (see paragraph A5.2.3.1).

A5.2.5. Increased measurement density over that given in paragraph A5.2.3.1 (for temperature or thickness) is only required during operating periods when the average thickness of the sea ice is nearing the point where it may limit gross aircraft weights and parking times for the aircraft type to be operated. For large aircraft, this will likely be the case any time first-year sea ice is encountered. See Attachment 2 for a description of the process for statistically establishing sea ice thickness.

A5.2.6. Approval and Documentation Storage. The certification team leader and the airfields manager will sign the final results from the data analysis. These signed documents and the electronic and hardcopy data and analysis results will be provided to and maintained by the airfields manager, and will also be provided to the certification team leader for forwarding to HQ AMC/A7OI.

CONVERSION FACTORS

TO CONVERT	TO	DIVIDE BY
LENGTH		
millimeters (mm)	inches (in)	25.4
centimeters (cm)	inches (in)	2.54
meters (m)	inches (in)	0.0254
meters (m)	feet (ft)	0.3048
meters (m)	yards (yd)	0.9144
kilometers (km)	miles (mi)	1.60948
AREA		
square millimeters (mm ²)	square inches (in ²)	645.16
square centimeters (cm ²)	square inches (in ²)	6.4516
square meters (m ²)	square inches (in ²)	0.00064516
square meters (m ²)	square feet (ft ²)	0.09290
square meters (m ²)	square yards (yd ²)	0.83613
square kilometers (km ²)	square miles (mi ²)	2.59043
square kilometers (km ²)	acres	0.00404
VOLUME		
cubic millimeters (mm ³)	cubic inches (in ³)	16,387
cubic centimeters (cm ³)	cubic inches (in ³)	16,487,000
cubic meters (m ³)	cubic feet (ft ³)	0.028317
cubic meters (m ³)	cubic yards (yd ³)	0.764559
MASS		
kilograms (kg)	pounds (lb)	0.45359
FORCE		
Newtons (N)	pounds (lbf)	4.44822
STRESS		
kiloPascals (kPa)	pounds per square	6.89476
TEMPERATURE		
Degrees Centigrade (°C)	Degrees Fahrenheit (°F)	Multiply by 1.8, then add 32

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